**Space Project Mission Operations Control Architecture (SuperMOCA)**

# SuperMOCA SYSTEM CONCEPT

**Volume 1**

# Rationale and Overview

January 1999

# *ORIENTATION*

The goal of the **S**pace **Pr**oject **M**ission **O**perations **C**ontrol **A**rchitecture ("SuperMOCA") is to create a set of implementation-independent open specifications for the standardized monitor and control of space mission systems. Monitoring is the observation of the performance of the activities of these systems. Controlling is the direction of the activities performed by these systems. Overall, monitor and control is the function that orchestrates the activities of the components of each of the systems so as to make the mission work. Space mission systems include:

spacecraft and launch vehicles that are in flight, and;
their supporting ground infrastructure, including launch pad facilities and ground terminals used for tracking and data acquisition.

The SuperMOCA system concept documents consist of the following:

SuperMOCA System Concept, Volume 1: Rationale and Overview
SuperMOCA System Concept, Volume 2: Architecture
SuperMOCA System Concept, Volume 3: Operations Concepts
SuperMOCA System Concept, Annex 1: Control Interface Specification
SuperMOCA System Concept, Annex 2: Space Messaging Service (SMS) Service Specification
SuperMOCA System Concept, Annex 3: Communications Architecture
SuperMOCA System Concept, Ancillary Document 1: Ground Terminal Reference Model
SuperMOCA System Concept, Ancillary Document 2: Operations Center to Ground Terminal Scenarios
SuperMOCA System Concept, Ancillary Document 3: Operations Center to Ground Terminal – Comparison of Open Protocols

These documents are maintained by the custodian named below. Comments and questions to the custodian are welcomed.

Michael K. Jones
MS 301-235
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
Voice: 818-354-3918
FAX: 818-354-9068
E-mail: michael.k.jones@jpl.nasa.gov

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# 1. Introduction

The Space Project Mission Operations Control Architecture ("SuperMOCA") project has the goal of developing open standard specifications for the monitor and control of space mission systems. The SuperMOCA addresses the mechanisms required to conduct a monitor and control dialog between a user (human or machine) and remote, distributed space mission systems. To operate these systems the user formulates directives, initiates their transmission, monitors their execution, and takes corrective action in case of anomalous behavior. The remote system executes the directives and provides status information. The systems which must be operated in a confederated manner in order to execute a space mission are:

- remote spacecraft and their payloads;
- launch vehicles which give those spacecraft access to space;
- launch complexes which support the launch vehicles;
- ground tracking and data acquisition stations which support the spacecraft and launch vehicles;
- Integration and test facilities which support the assembly of the spacecraft and launch vehicles;
- Operations centers which support the flight of the spacecraft and launch vehicles.

The SuperMOCA task embraces both an **architecture** and the specification of **standards** which enable the architecture to be applied across multiple space mission systems.

The architectural **"A"** part of SuperMOCA is broad. It recognizes that space mission monitor and control is a complex process involving many different activities, systems and technologies.

The control **"C"** part of SuperMOCA is currently specialized. It focuses on developing standards for device monitor and control, i.e., the supervision and operation of the set of controllable devices scattered across space and ground systems that must be orchestrated in order make the overall mission work.

## 2. The Problem Addressed by SuperMOCA

A dramatic change is occurring across many segments of the space community, driven by shrinking government budgets and new emphasis on developing commercial markets. Dimensions of the change include:

- a shift towards decentralization in mission strategy, with movement away from "a few expensive spacecraft launched relatively infrequently" and towards "many affordable spacecraft launched relatively often";
- a need to significantly reduce the costs of operating the increased numbers of small spacecraft without sacrificing either mission flexibility or capability;
- advances in space microelectronics which allow increased automation[1] and autonomy[2] to be packaged into small spacecraft that can be deployed using less expensive launch vehicles. With these advances, the scope and complexity of the remaining human user operations may be significantly reduced. Reduced human operations complexity reduces operations costs and increases reliability.
- the emergence of new commercial space operators (often using constellations of satellites) who, driven by the profit motive, seek low-cost "off the shelf" monitor and control systems that reduce the need for capital and operating investment;
- increasing reliance on cooperation (both national and international) to achieve complex space mission objectives in ways that are affordable to individual organizations, with emphasis on reducing wasteful duplication of effort and improving mission effectiveness by sharing infrastructure and capabilities through the promotion of interoperability between the civil, military, and commercial space sectors.

Standardization is a well recognized tool in addressing the dilemma of increasing requirements on system complexity and decreasing resources to develop systems. Recognition of the value of standards has already led to the standardization of intercommunication of data between spacecraft and their supporting ground systems. However, the data intercommunication simply addresses the physical means of data transport.

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[1] In this document the term automation is used to indicate that an application will execute a set of pre-defined actions upon the receipt of an event or timeout.

[2] In this document the term autonomy is used to indicate that an application will take actions based on its knowledge of itself and/or its surroundings given a set of conditions (pre-defined rules, targets of opportunity, ...).

## SuperMOCA Rationale and Overview

Large gains can now be realized by focusing upon the standardization of mission system applications that use the underlying and standardized communications services. These mission system applications are large cost drivers in the implementation of space and ground resources. Specifically, the monitor and control of spacecraft and their supporting ground networks is an application that is ready for standardization. Currently lacking standards or guidance (and the corresponding availability of inexpensive commercial products), space mission monitor and control is significantly re-invented for each mission. This results in high costs and customized, labor intensive operations. Even with today's spacecraft containing vastly increased on-board capabilities and resources, spacecraft are still extensively managed from the ground.

Applying the SuperMOCA Architecture and its associated standards to the "next generation" space missions discussed above will result in monitor and control capabilities that:

Present a consistent view to the user of space mission systems being monitored and controlled

Facilitate migration of automated and autonomous functions from operations centers to remote space mission systems

Facilitate sharing of monitor and control resources among space missions

Facilitate insertion of new technology into existing monitor and control capabilities

Promote the use of commercial monitor and control applications and commercial components in space mission systems

As will be discussed in detail in the next two sections, SuperMOCA advocates that commercial technologies incorporated into an architecture for space mission system monitor and control allow for a low cost and low risk approach to future spacecraft missions. SuperMOCA promotes automated and autonomous operations while enhancing the user's flexibility and independence from knowing detailed system implementations. It provides users with standard consistent interfaces that enable them to monitor and control remote, distributed space mission systems at reduced operational costs. Many individual off-the-shelf technologies exist which can contribute to solving space exploration's complex problems, but they usually require integration to make them useful. Where integrated solutions do exist, they tend to be proprietary and are therefore incompatible with the need to drive down space mission costs by encouraging competition. The goal of SuperMOCA is to establish an overall open systems architecture and corresponding set of specifications within which diverse commercial products may develop in a common marketplace for space mission monitor and control. The SuperMOCA can help usher-in an era of commercial competition that will drive down costs as project designers select from diverse set of commercial products that conform to fully-open interface standards.

# 3. SuperMOCA Overview

## 3.1 Monitor and Control of Space Mission Systems

SuperMOCA applies to the monitor and control dialogues used to execute space missions. These monitor and control dialogues connect the user with:

ground systems (including ground terminals and launch complexes),

spacecraft engineering systems (including launch vehicles)

spacecraft payloads (i.e., instruments and experiments)

SuperMOCA defines a consistent way to conduct monitor and control dialogues for space missions. Figure 3-1 illustrates this monitor and control dialogue between a user and a space mission system. The dialogue with the remote system is supported by the underlying data communications capabilities that connect the user with the space mission system. Note that in SuperMOCA a "user" may be an automated or autonomous monitor and control application. More details on the several architectural views of this monitor and control dialogue can be found in the SuperMOCA System Concept, Volume 2: Architecture.

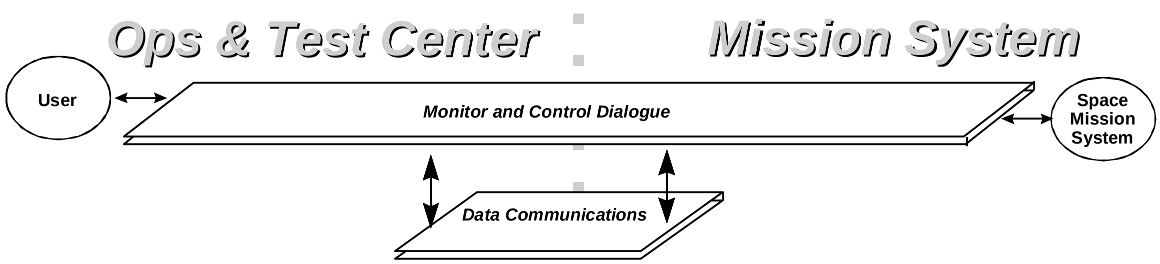


**Figure 3-1 - Space Mission Monitor and Control Dialogue**

## 3.2 SuperMOCA Elements: Technologies and Standards

The problems encountered in conducting space mission monitor and control dialogues are not unique. Similar problems have been addressed by the industrial process control and manufacturing automation communities. There is a striking similarity between the critical automated control systems that operate oil refineries and those that operate spacecraft and launch complexes. Controlling and orchestrating the robots that operate on automobiles as they flow through a fully automated factory is similar to operating a large tracking station, or supervising rovers on Mars. SuperMOCA assimilates the off the shelf technologies from these industries, integrates them into a cohesive set of monitor and control capabilities for space mission systems, and makes these standard capabilities rapidly available for widespread application across the civil, military and commercial space community. SuperMOCA advocates the use of technologies associated with open standards and featuring distributed computing concepts. This allows the SuperMOCA infrastructure to be distributed across multiple hosts, multiple geographically distributed facilities, and multiple organizations. Currently SuperMOCA is focused on the use of commercial technology for the monitor and control of devices. Consequently, the elements of SuperMOCA described below apply only to the monitor and control of devices in space mission systems. This cohesive set of monitor and control capabilities includes the following:

standard device interfaces that isolate the specifics of vendor-specific device designs from the user and monitor and control applications

a message service to support the exchange of monitor and control information between users and the devices,

a user language for monitor and control of the devices, (This is in addition to the graphical user interface that is assumed, but not standardized, in SuperMOCA.)

a standard environment for applications that prevent directives that would damage the devices from being executed

standard mechanisms for describing the monitorable and controllable attributes of the devices and exchanging this descriptive information between monitor and control applications

There are 5 elements of SuperMOCA. A “top” view of these elements nested together is shown in Figure 3-2 and briefly explained below. More details on these standards and technologies can be found in the SuperMOCA System Concept, Volume 2: Architecture.

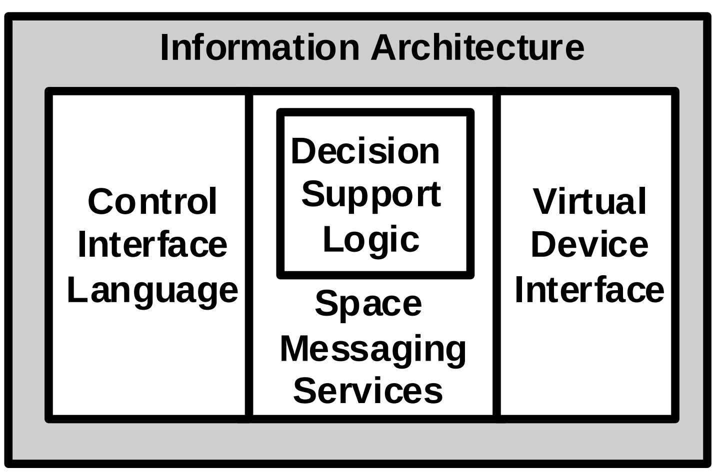


**Figure 3-2 - "Top" View of the Elements of SuperMOCA**

- Control Interface Language - At the user interface, this is a text-based, test and mission operator-oriented language allowing the mission operator to monitor and control activities of remote space mission resources.

- Decision Support Logic - These are the standardized interfaces to capabilities that preserve mission resource health by preventing any control commands from being executed that would damage the resource.

- Space Messaging Service - This provides a standard set of messaging services that are the mechanisms used to monitor and control a set of virtual devices.

- Virtual Device Interface - At the device interface, this is a standard representation of the externally-visible aspects of the device that can be monitored and controlled.

- Information Architecture - This is the standardized structure into which the monitorable and controllable characteristics of devices can be captured and used to configure the generic capabilities of SuperMOCA for the specific mission.

Four of these elements (the Control Interface Language, the Decision Support Logic, the Space Messaging Service, and the Virtual Device Interface) are used to conduct the monitor and control dialogues. The fifth element (the Information Architecture) supplies descriptive information that is used to configure the other elements to monitor and control a specific set of devices. See Figure 3-3 for a layered "side" view of these elements. This figure shows these elements distributed between space and ground portions of a space project. The three elements in the monitor and control dialogue depend on underlying data communications of the space mission. They also depend on the Information Architecture element which is shown as a foundational layer of the architecture.

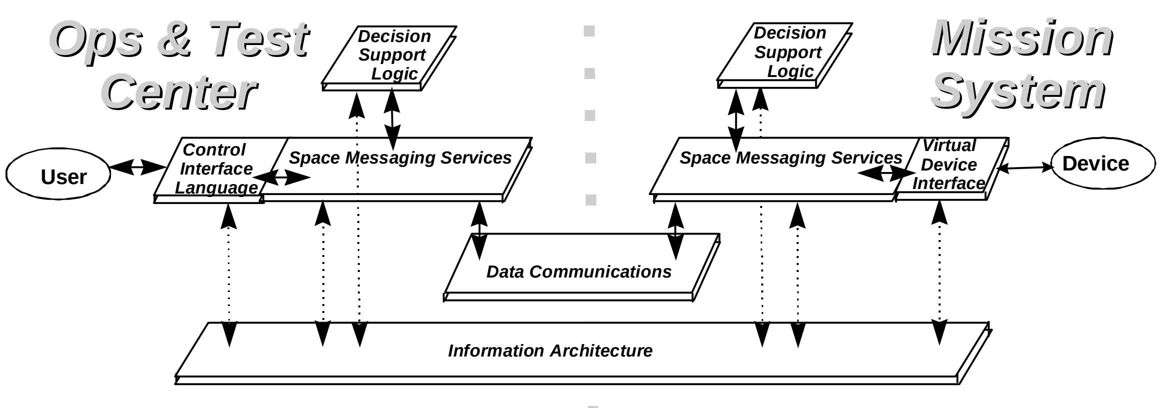


**Figure 3-3 - "Side" View of the Elements of SuperMOCA Distributed Between Space and Ground**

Figure 3-4 shows an example of the roles of these SuperMOCA elements in a monitor and control dialogue between a user and a device on a spacecraft (a particular make and model of fluid valve, which is a component of a cooling subsystem). This monitor and control dialogue proceeds with the following numbered steps in the figure.

1. The user formulates a high-level request to initiate cooling of an infrared spectrometer on a spacecraft at 1600 hours on the next day.

2. The Control Interface Language interpreter expands this request (using device descriptive information in the Information Architecture, not shown in figure) into a series of directives to remote objects in the virtual valve device. It also translates the directives into variable assignments (again using device descriptive information in the Information Architecture) and execution times.

3. The Space Messaging Services encapsulate the variable assignments and execution times into a standard message that is to be sent to the virtual valve device on the spacecraft.

4. The Decision Support Logic checks the safety of this activity, considering the overall system state as predicted for 1600 hours on the next day.

5. If “safe”, this message is transported to the spacecraft using the ground-to-space communications system of the space mission.

6. The Virtual Device Interface translates the variable assignments into specific concrete actions at the specified time, such as applying specific voltage to particular pins controlling the valve.

7. The valve issues a status by applying a specific voltage to a particular pin.

8. The Virtual Device Interface translates the voltage into a variable value.

9. The Space Messaging Services encapsulate the variable value into a standard message that is sent to the user.

10. This message is transported to the ground using the ground-to-space communications system of the space mission.

11. The Control Interface Language interpreter translates the variable value in this message (using device descriptive information in the information architecture) into a status notification to the user.

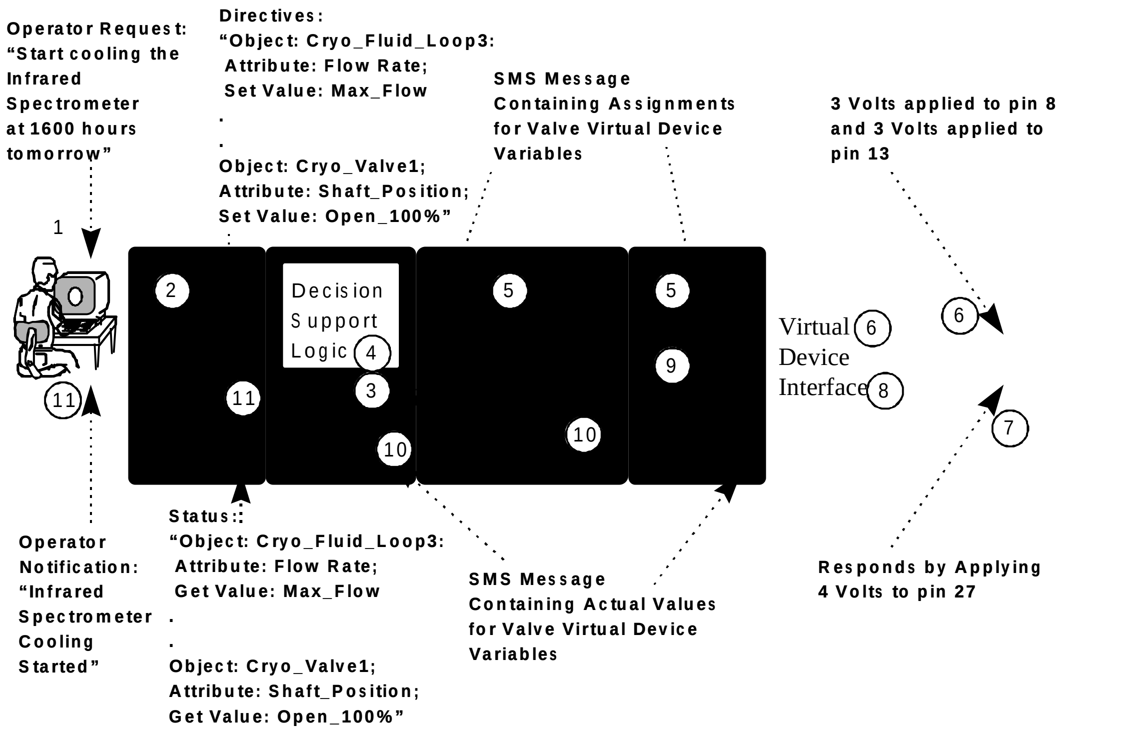


**Figure 3-4 - An Illustrative SuperMOCA Monitor and Control Dialogue**

The SuperMOCA elements can be used to conduct a monitor and control dialogue with any device in any system used by a space mission. It could be a spacecraft fluid valve, a pyrotechnics controller on a launch vehicle, a liquid hydrogen pump on a launch tower, or an antenna pointing mechanism in a ground tracking station. There are many possible variations for executing this dialogue allowed within the SuperMOCA Architecture. For instance, the "user" could be an automated or autonomous monitor and control application. Other examples are that the Decision Support Logic could be wholly located on the spacecraft or could be distributed between ground and space.

# 4. SuperMOCA Benefits: Life Cycle Cost Reduction

The main cost reduction feature in SuperMOCA is the use of commercial products that are cheaper than “in-house” products to acquire, operate, and maintain and, as well, are more reliable. They are cheaper because product development and improvement costs are amortized over a large customer base. They are more reliable because the large customer base detects problems and feeds back information to the vendors to improve product reliability. In general, costs throughout the mission life cycle can be reduced by the adoption of SuperMOCA open standards. Initially, SuperMOCA will provide the common understanding and open standards to facilitate the migration from in-house products to adopted or adapted commercial products. As more experience is gained in the use of these standards more costs will be saved. In the long run, widespread use of these standards will promote a commercial market for space mission monitor and control products.

Sections 4.1, 4.2, and 4.3 discuss some additional specifics on how SuperMOCA will achieve cost reductions in the following phases of the mission life cycle: Development, Integration & Test, and Operations & Maintenance. More details on the role of SuperMOCA in the mission life cycle can be found in the <u>SuperMOCA System Concept, Volume 3: Operations Concept</u>.

## 4.1 Development Costs

SuperMOCA addresses the following causes of the current expense of space mission system development:

Design description information is repeatedly ported from one design tool-specific format and syntax to another during design and from system developers to system testers and to operators at the end of the development cycle.

Monitor and control applications for space mission systems are designed anew for the particular system or are inherited from other systems and extensively modified.

Devices inherited from other space mission systems must be extensively reworked to make them compatible with current space mission system interfaces and monitor and control methods.

With the SuperMOCA architecture and standards in place, developers will reduce cost by designing to only one monitor and control architecture with one set of standard interfaces. Additional cost reductions in the development phase will occur due to the following.

- Use of the “virtual device” concept for space mission systems will remove vendor-specific design peculiarities that would otherwise affect the monitor and control system design from the system designers

- Use of the Space Messaging Services standards will provide the designer with an already system-engineered solution for monitor and control functionality needed for any space mission system.

Use of the Information Architecture will allow developers to describe the monitorable and controllable behavior of devices using a standardized method and capture the descriptive information in a standardized data structure. It will provide a standard mechanism for exchanging this information between design tools.

## 4.2 Integration & Test Costs

SuperMOCA addresses the following causes of the current expense of space mission system integration and test (I&T).

- Device interfaces frequently fail upon initial integration because they are unique and, therefore, untried.

- Test conductors need extensive training on the specifics of mission system devices in order to conduct system tests. If this level of training is not feasible, then device design experts are frequently required to support integration and test.

- Inconsistent user interfaces and methods for monitoring and controlling systems force complexity into test conductors jobs and/or into test monitor and control applications.

With the SuperMOCA architecture and standards in place, test conductors will use one user interface language. Standard monitor and control interfaces and more reliable devices and test monitor and control applications (incorporating increased automation and autonomy) will shorten test schedules and reduce costs. Additional cost reductions in I&T phase will occur due to the following.

Use of the Control Interface Language will allow test conductors to direct and monitor test activities using an English-like language. The Control Interface Language using device description data in the Information Architecture will translate to and from low-level monitor and control syntax.

Use of the “virtual device” concept will hide vendor-specific design peculiarities from the user to make devices appear similar in terms of monitor and control.

Use of the Space Messaging Services standards will give the test conductor a standard set of monitor and control services that are built into the virtual devices and any test monitor and control applications.

Expanding the use of the virtual device concept to include self-identifying devices for integration and test will enable each device to talk to the system as soon as it is connected. Each device will identify itself and its monitorable and controllable features and the Space Messaging Services it understands. The descriptive data from the device will be structured according to the Information Architecture standard. The test monitor and control applications can be automatically configured upon connection to manipulate the self-identified device.

Use of Decision Support Logic procedures, algorithms, and/or reasoning engines will prevent any directives from being executed that would damage the devices. These capabilities will check the current state of the device as well as notify the test conductor of any preventative actions taken.

## 4.3 Operation & Maintenance Costs

SuperMOCA addresses the following causes of the current expense of space mission system operations and maintenance (O&M).

- Operators need extensive training on the specifics of mission system devices in order operate and maintain mission systems. If this level of training is not feasible, then device design experts are frequently required to support integration and test.

- Inconsistent user interfaces and methods for monitoring and controlling systems force complexity into operations jobs and/or into monitor and control applications.

Having the SuperMOCA architecture and standards in place will provide consistent monitor and control interfaces, methods, and applications (incorporating increased automation and autonomy) between system I&T and mission operations. This will reduce operator training and dependence on the use of experts in O&M. Additional cost reductions in O&M will occur due to the following.

Use of the Control Interface Language will allow operators to direct and monitor mission activities using an English-like language. The Control Interface Language using device description data in the Information Architecture will translate to and from low-level monitor and control syntax.

Use of the “virtual device” concept will hide vendor-specific design peculiarities from the user to make devices appear similar in terms of monitor and control.

Use of the Space Messaging Services standards will give the operator a standard set of monitor and control services that are built into the virtual devices and any monitor and control applications.

Use Decision Support Logic procedures, algorithms, and/or reasoning engines will prevent any directives from being executed that would damage the devices, both on the ground and in space. These capabilities will check the current state of the device as well as notify the user of any preventative actions taken.